An Integrated Systems T&E Approach

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Dean Carico, NAVAIR 4.11.3.2
Rotary Wing Ship Suitability
Patuxent River, MD

OUTLINE

- T&E Overview
- Past T&E Focus
- Current T&E Emphasis
- T&E Complexity Changes
- T&E Engineering Options
- Integrated Systems T&E Approach
- Operational Scenario
- Summary

T&E Overview

- DoD Procurement Funds
- Current Cost of Rotorcraft Testing
  - Becoming more expensive
  - May uncover problems late in acquisition cycle
- Mission Rehearsal Training
  - OFT/WST Expensive
  - Far removed from battlefield site
- Acquisition & Mishap Investigations
  - Not integrated with flight testing

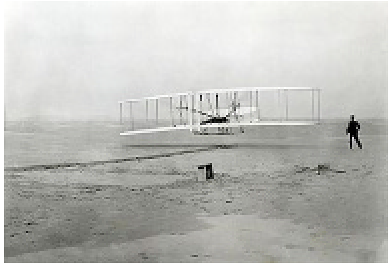
Past T&E Focus - Cost and Cycle Time

- **NAWCAD 4.11 BPR POC for T&E**
  - Jun 99 - Need to reduce T&E costs by 33% & cycle time by 50%
- **DR. JACQUES GANSLER - Into the 21st Century - A Strategy for Affordability**
  - JAN 1999 - …We must further adapt the best world class business and technical practices to our needs, ... and reduce cycle times and ownership costs while simultaneously improving readiness
- **DR PAT SANDERS - ITEA JOURNAL**
  - JUN/JUL 1998 - The cost of testing can, and should be, reduced through the use of credible simulation

Current T&E Emphasis

- **Interoperability**
  - The ability of systems to provide services to and accept services from other systems
  - DoD 5000 series requires that all systems must be designed and tested to ensure interoperability
- **System-of-Systems (SoS)**
  - A system working with a group of other systems or sub-systems in a seamless environment

T&E Complexity Changes



- Wright Flyer – 1903
- Sikorsky R-4 Helicopter – 1942
- Sikorsky SH-60B LAMPS MK3 – 1983
- Bell Boeing V-22 – 1989
- Lockheed Martin JSF – 2000

T&E Engineering

- Focus
  - Avionics; Design; Engines and Power Trains
  - Flight Dynamics; Flight Controls
  - Performance; Structures and Loads
  - Ship Suitability
- Matrix Organization
  - Advantage: Technical Specialties
  - Disadvantage: “Rice Bowls” – Very difficult to get project approved that benefits everyone

T&E Options

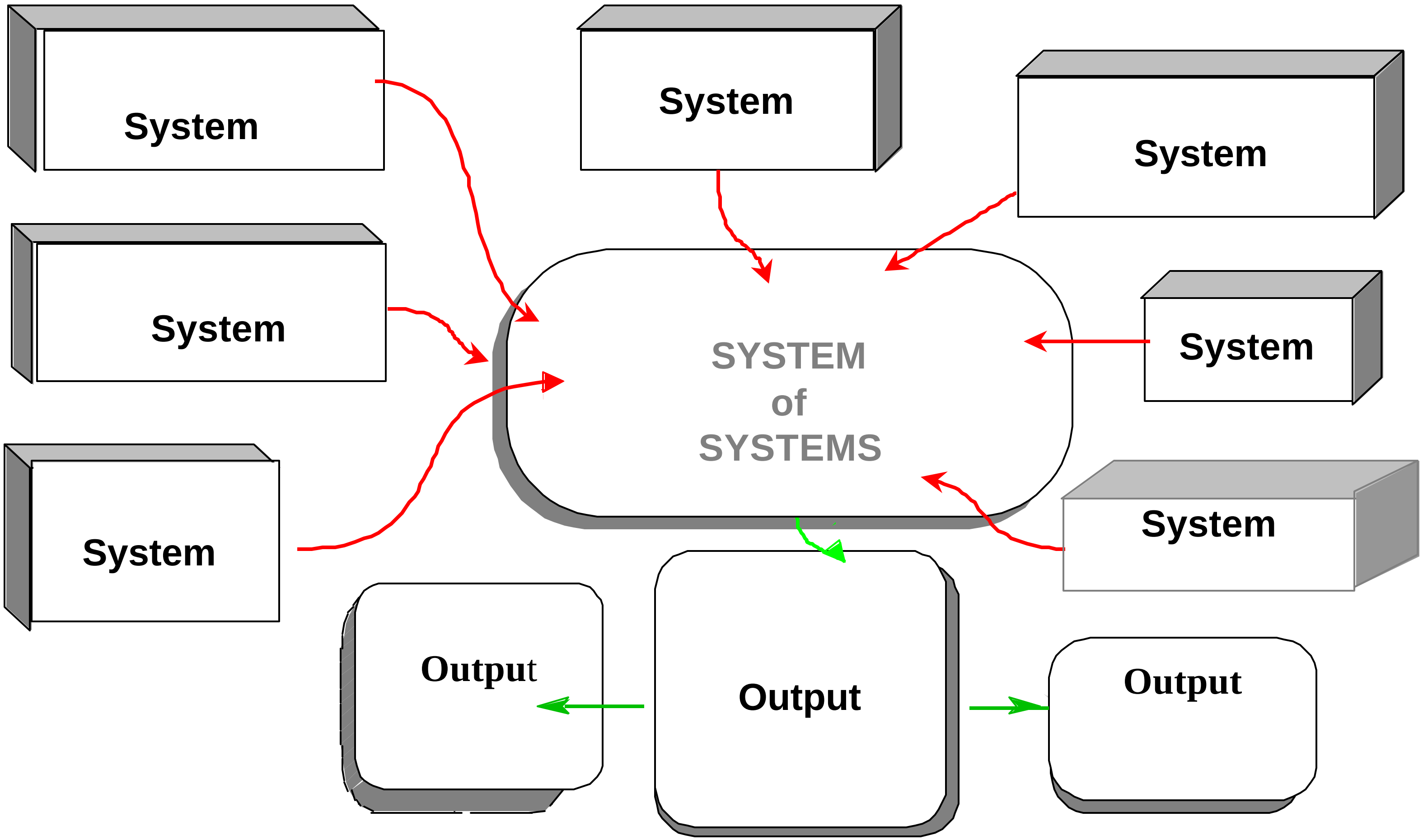
- Business as usual - Conventional T&E
  - Introduction of personal computer in the 1980’s
  - Introduction of the WWW in the 1990’s
  - Cost & Cycle Time Problems
- Combine Conventional T&E and Virtual T&E using related technology options
  - Develop and validate an analytic capability to support and enhance conventional T&E

DoD 5000.2-R Requirements

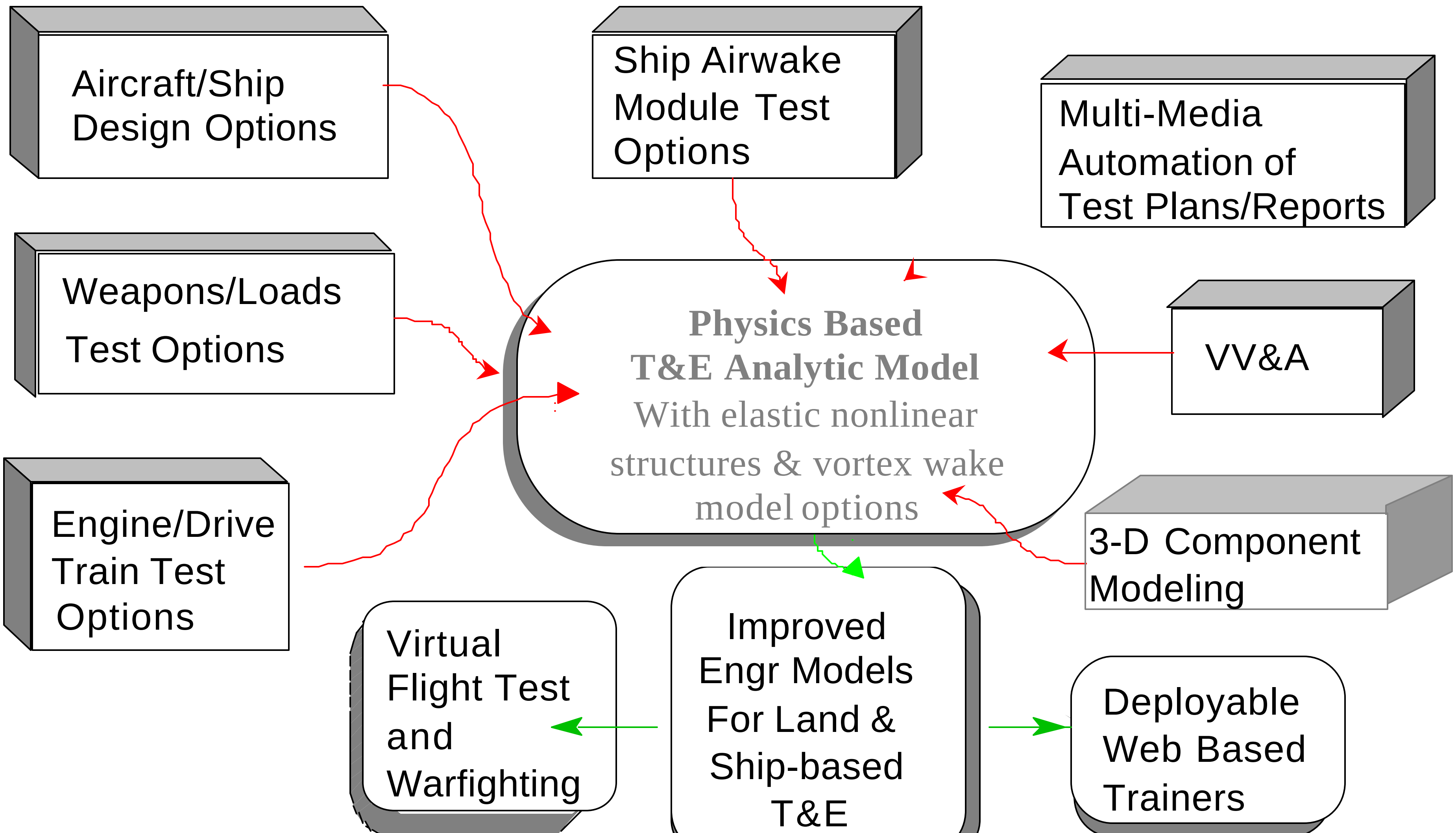
(5 Apr 2002)

- **C1.1 Modeling and Simulation**
- The PM shall identify and fund required M&S resources early in the acquisition life cycle, so M&S may be integrated with the T&E program
- The PM shall use test results to revise both the test program and test procedures
- Test results shall also be used to develop and improve models and simulations

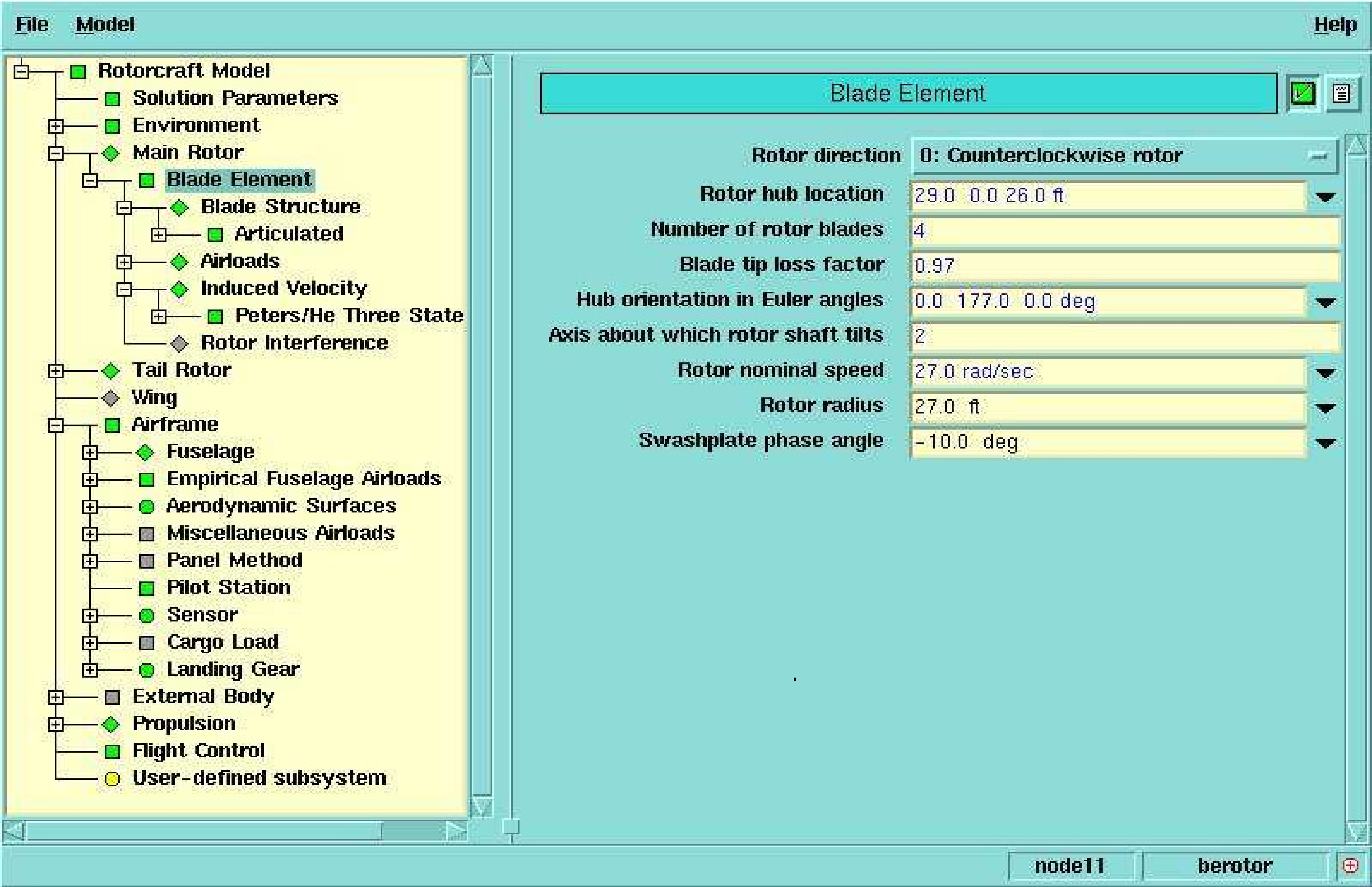
System of Systems (SoS) Approach



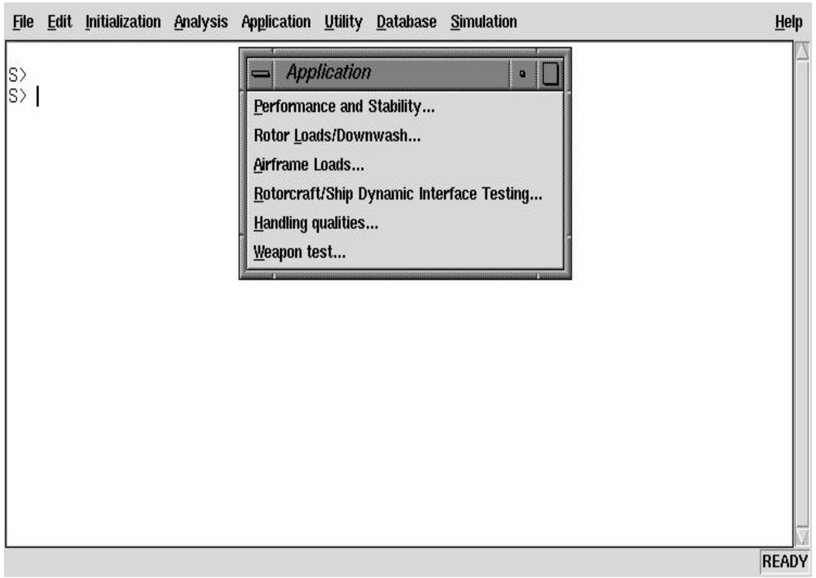
SoS T&E Approach

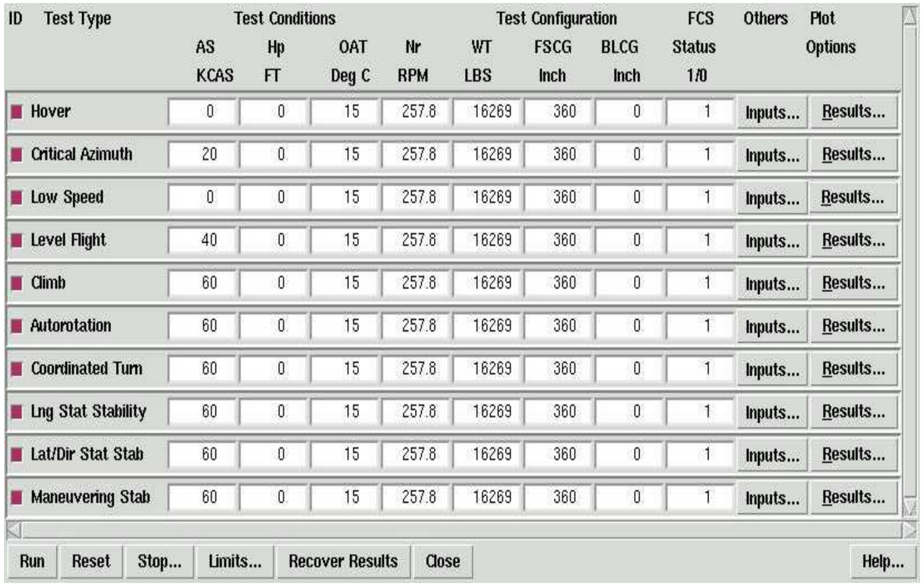


Physics-based T&E Analytic Model (Flightlab)

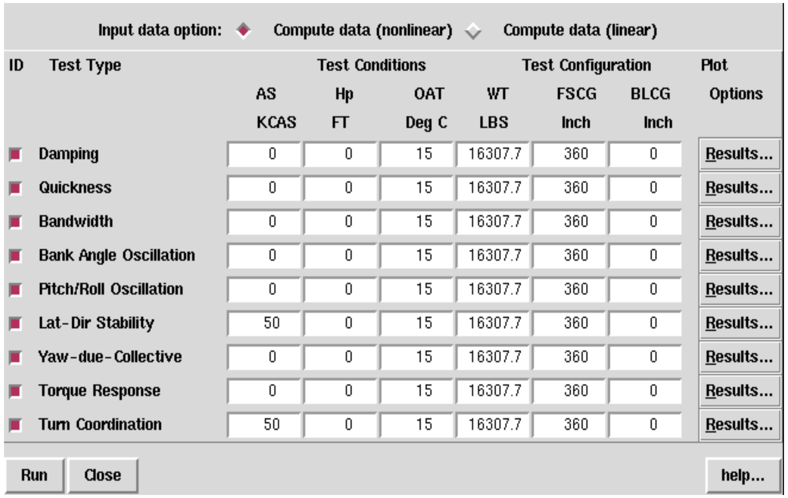


Analytic Flight Test Support Options

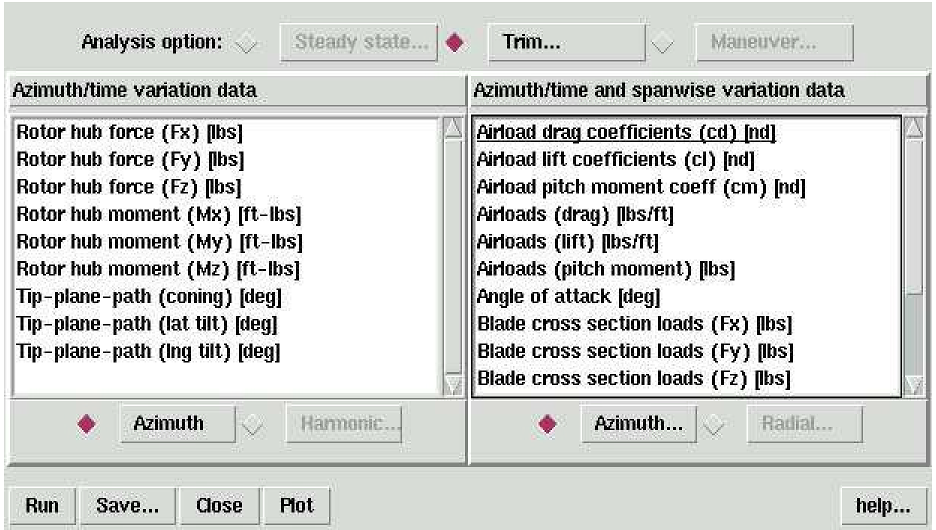




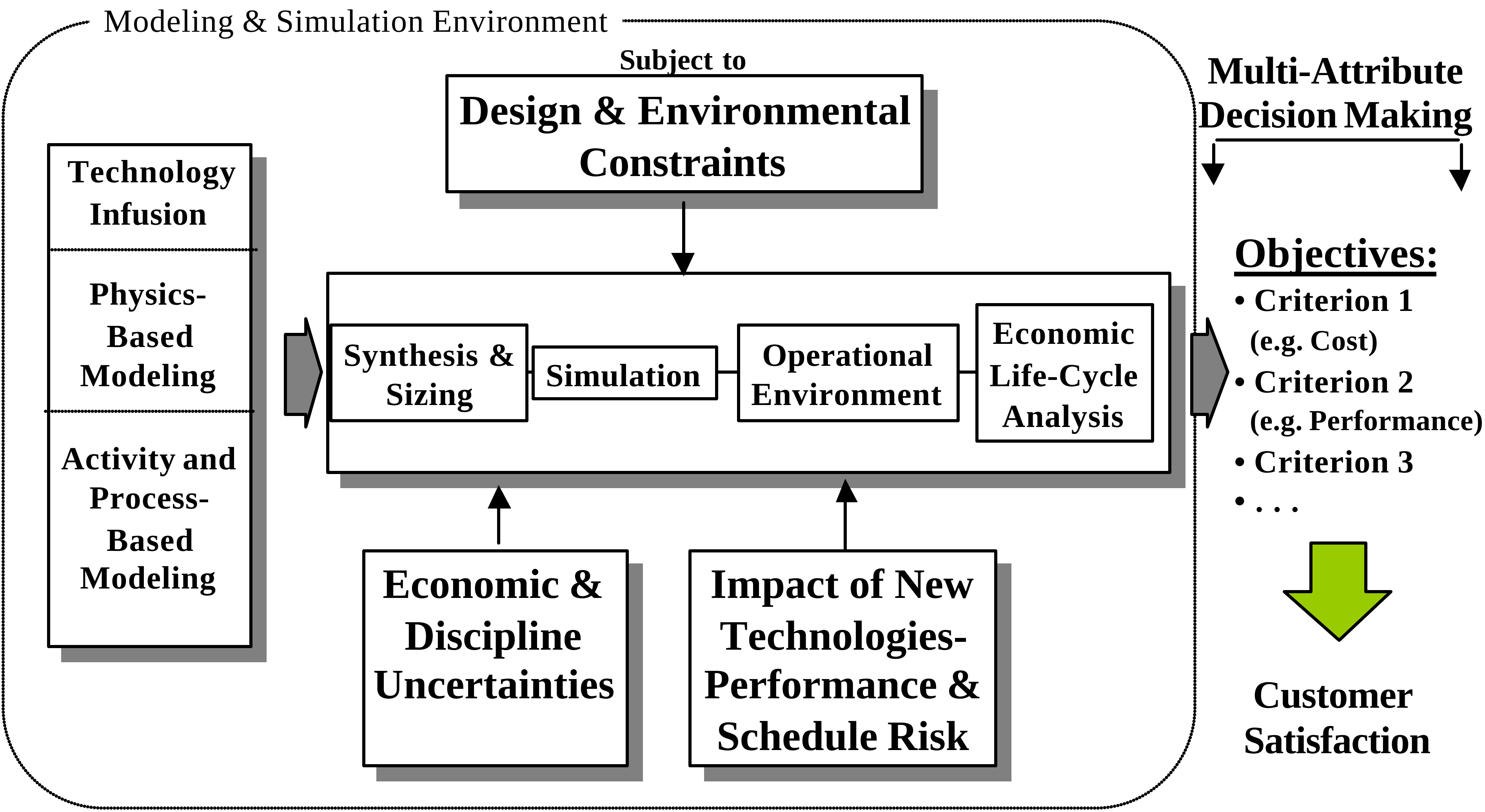
ID	Test Type	Test Conditions AS KCAS	Hp FT	OAT Deg C	Nr RPM	Test Configuration WT LBS	FSCG Inch	BLCG Inch	FCS Status 1/0	Others	Plot Options
■	Hover	0	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Critical Azimuth	20	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Low Speed	0	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Level Flight	40	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Climb	60	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Autorotation	60	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Coordinated Turn	60	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Lng Stat Stability	60	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Lat/Dir Stat Stab	60	0	15	257.8	16269	360	0	1	Inputs...	Results...
■	Maneuvering Stab	60	0	15	257.8	16269	360	0	1	Inputs...	Results...



ID	Test Type	Test Conditions AS KCAS	Hp FT	OAT Deg C	Test Configuration WT LBS	FSCG Inch	BLCG Inch	Plot Options
■	Damping	0	0	15	16307.7	360	0	Results...
■	Quickness	0	0	15	16307.7	360	0	Results...
■	Bandwidth	0	0	15	16307.7	360	0	Results...
■	Bank Angle Oscillation	0	0	15	16307.7	360	0	Results...
■	Pitch/Roll Oscillation	0	0	15	16307.7	360	0	Results...
■	Lat-Dir Stability	50	0	15	16307.7	360	0	Results...
■	Yaw-due-Collective	0	0	15	16307.7	360	0	Results...
■	Torque Response	0	0	15	16307.7	360	0	Results...
■	Turn Coordination	50	0	15	16307.7	360	0	Results...



Robust Design Simulation



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Weapons & Loads Testing

- Weapons
  - Guns
  - Missiles & Rockets
  - Bombs
- Loads
  - Steady
  - Vibratory

AEDC Engine Modeling

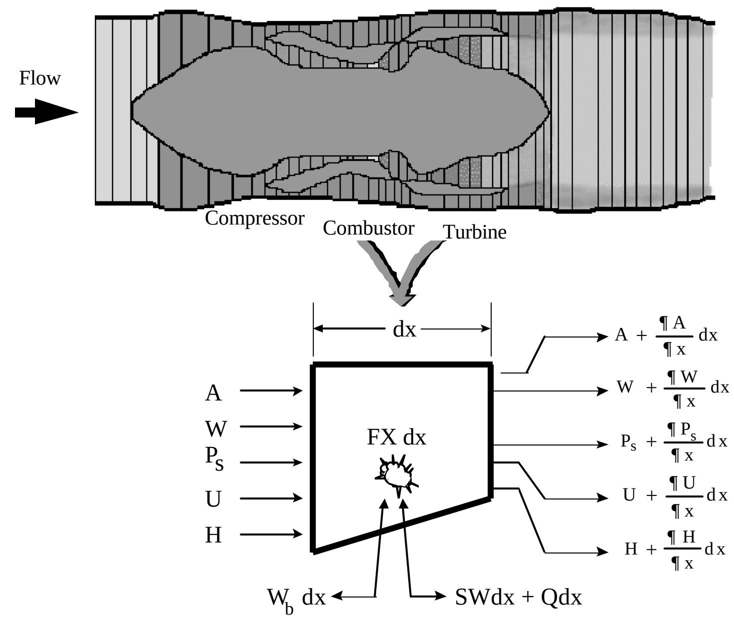
- The Aerodynamic Turbine Engine Code solves the 1-D Euler Equations with Turbomachinery Source Terms across elemental control volumes:

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}}{\partial x} = \mathbf{G}$$

where:

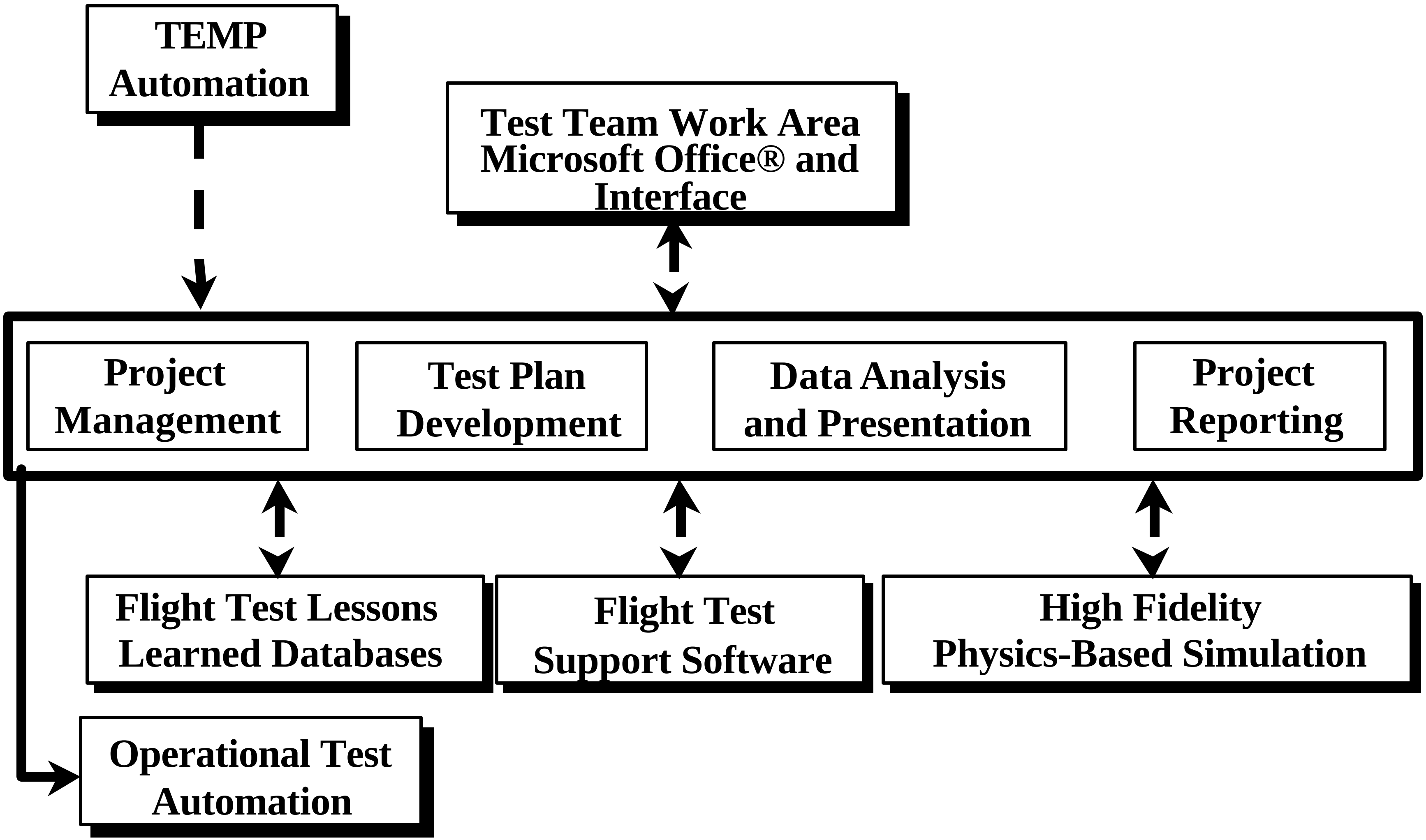
$$\mathbf{U} = \begin{bmatrix} Ar \\ rAu \\ AE \end{bmatrix} \qquad \mathbf{F} = \begin{bmatrix} rAu \\ rAu^2 + AP \\ u(AE + AP) \end{bmatrix} \qquad \mathbf{G} = \begin{bmatrix} -W_{B_x} \\ F_x \\ Q_x + SW_x - H_{Bx} \end{bmatrix}$$

- Variable time-stepping routine using both explicit and implicit numerical solvers ensures efficient transient simulation with high fidelity dynamic simulation



Discretization of system into elemental control volumes

Flight Test Automation

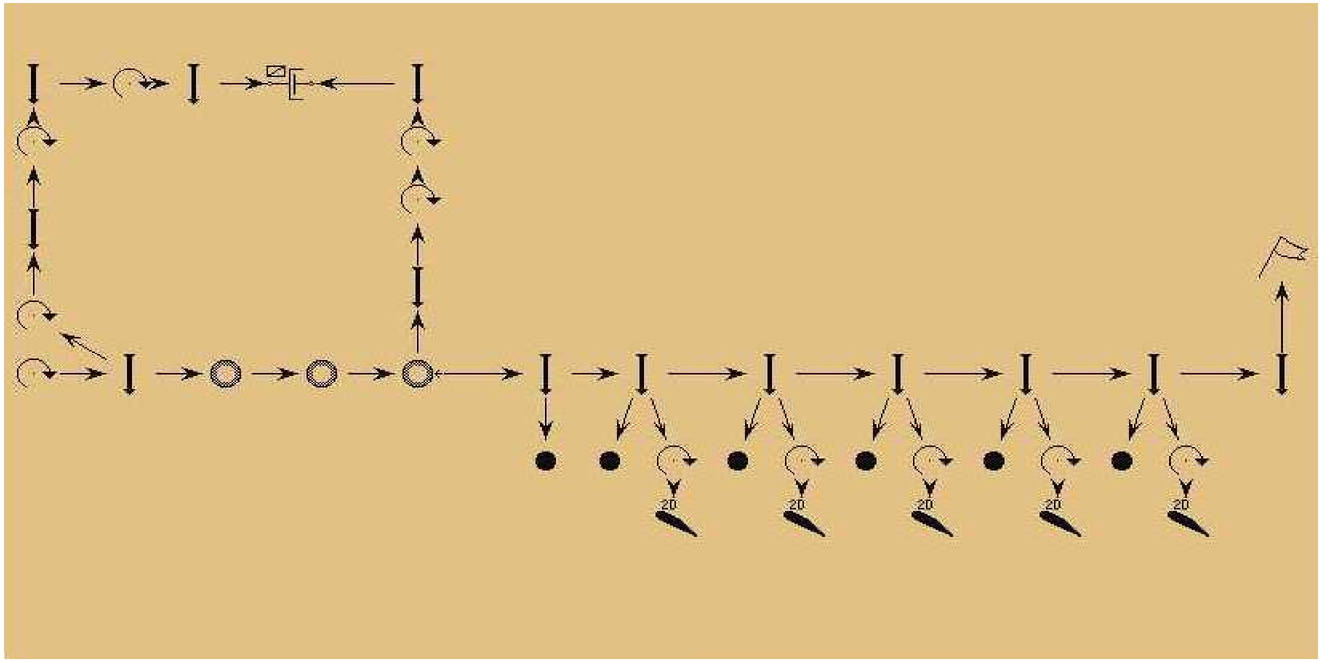


VV&A

- **Required**: Sanity check of model structure
- **Verification** - Was model programmed and/or implemented correctly?
- **Validation** - How close does model compare with real world data?
- **Accreditation** - Process of approving model for specific applications
- **Built-in V&V options**

3-D Component Modeling

- Flight Test Engineers work in a 3-D world
- Rotorcraft fly in 3-D world
- Model development & analysis in 2-D

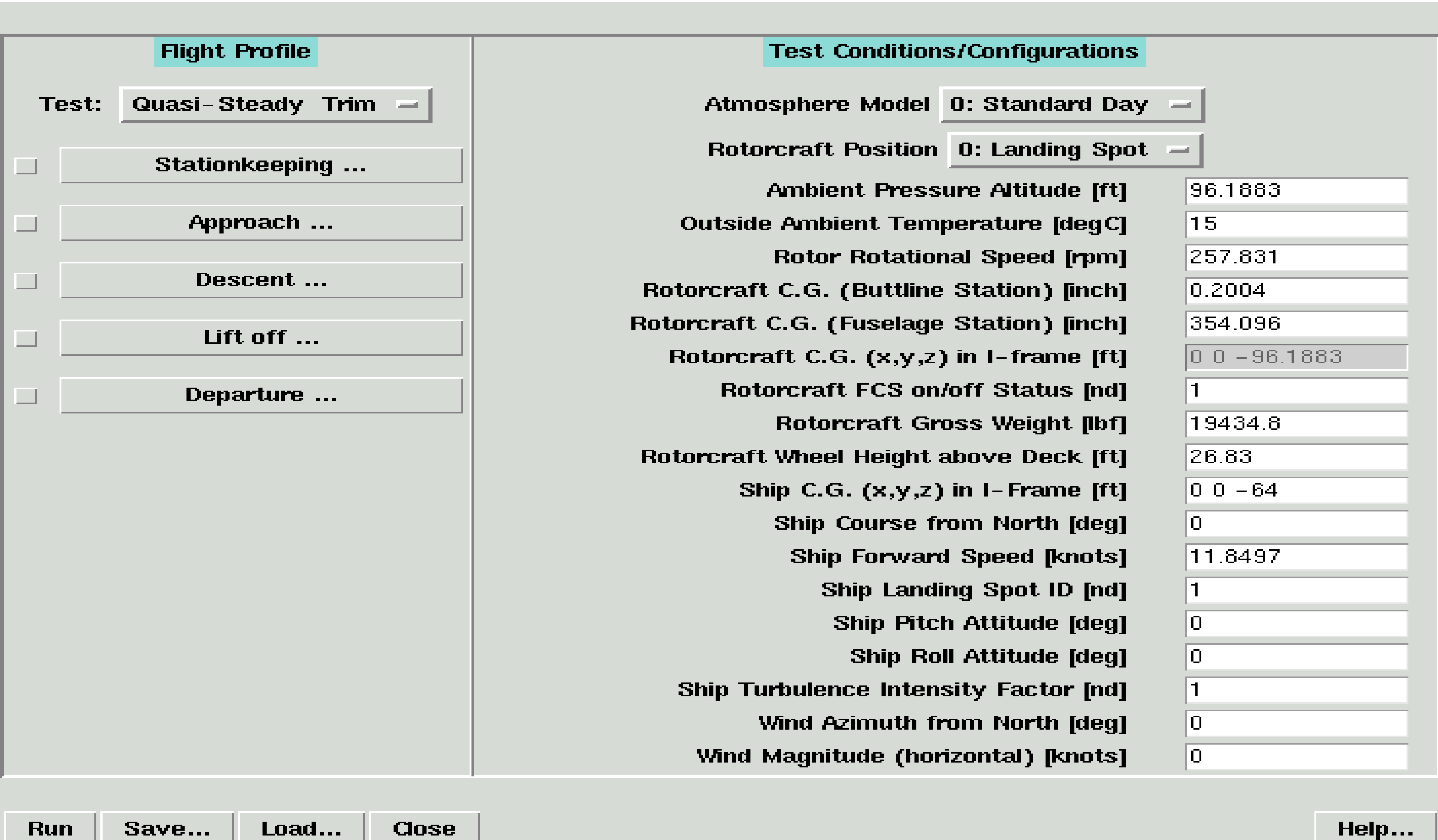


Dynamic Interface (DI) Rotorcraft/Ship Operational Challenges

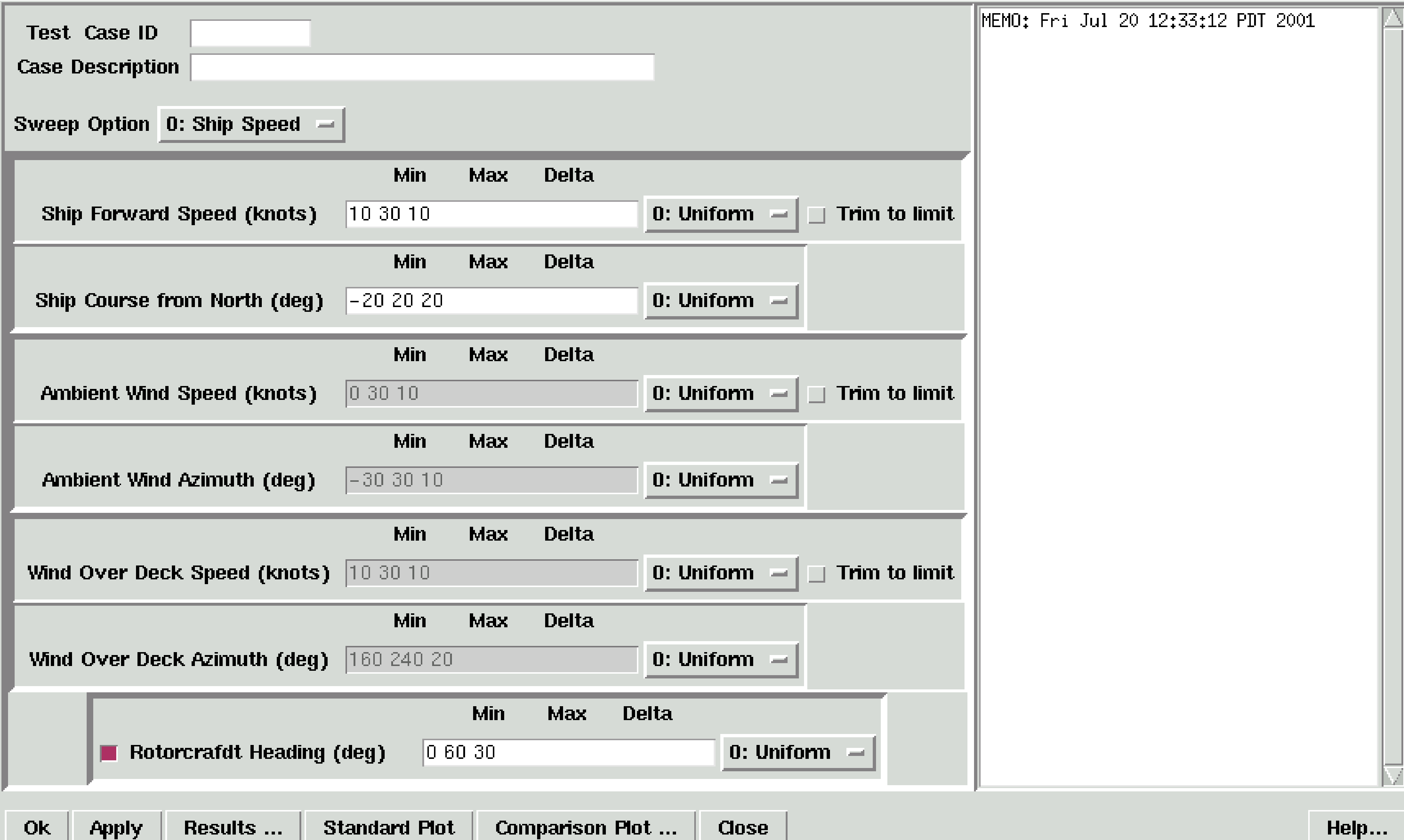
Shipboard Rotorcraft Operation Environment

- High & Turbulent Winds
- Possible Low Visibility Condition
- Moving & Confined Landing Platform
- Unusual Airwake Over the Deck of Ship

GUI for DI Flight Profiles



DI Stationkeeping



Summary

- Conventional T&E methodologies applied to early aircraft were not designed to share information
- The complexity of modern aircraft combined with limited budgets dictates interoperability and SoS approaches to T&E
- An integrated systems approach to T&E could be used to not only help reduce the cost and cycle time of testing, but would also support the issues of interoperability and systems of systems testing